DOE/ET-0055

Preliminary Estimates of the Charge for Spent-Fuel Storage and Disposal Services

July 1978

U.S. Department of Energy
Assistant Secretary for Energy Technology
and Director of Energy Research
Washington, D.C. 20545

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FOREWORD

The purpose of this report is to stimulate discussion among a wide range of interested parties concerning a one-time charge by the U.S. Government for disposal, or interim storage and disposal, of spent unreprocessed nuclear fuel. The report contains a set of estimates of the charge based on current cost figures and a variety of demand, logistical, institutional, and cost overrun assumptions.

The services are to be offered to domestic utilities by the U.S. Government in connection with the spent fuel policy approved by the President and announced by the Department of Energy (DOE) on October 18, 1977. This policy is a direct result of the indefinite deferral of all commercial reprocessing of spent fuel announced by President Carter on April 7, 1977. The services will also be offered to foreign governments on a limited basis in cases where this action would contribute to U.S. goals for nonproliferation of nuclear weapons.

The report does not establish new policy and it does not commit DOE to any specific program, schedule or charge. No scenario or case is to be considered most important, no methodology is to be considered definitive, and no charge is to be considered most likely or to represent a proposed charge.

The report describes basic principles and methodologies for calculating the charge and highlights primary cost centers. Current estimates of program and facility costs are used. Various aspects of the DOE Spent Fuel Storage Program are brought into focus through this analysis. Interested parties should find these assessment criteria helpful for their planning and useful in discussions concerning the program. The results of these discussions

transmitted to DOE will be a contributing factor in DOE planning for the establishment of a charge for spent fuel disposal and interim storage services.

A Draft Generic Environmental Impact Statement (GEIS) will be issued shortly evaluating the environmental impacts associated with the interim management of domestic spent fuel. Another Draft GEIS on the U.S. offer to accept and store limited quantities of foreign fuel is currently being written. A third Draft GEIS is being prepared concerning the environmental impacts of alternative approaches to establishment of charges associated with accepting spent fuel for storage and disposal.

Public comment received at DOE on this report will serve as one source of input to the GEIS concerning the charge. The results of all of the Environmental Impact Statements must be reviewed pursuant to the National Environmental Policy Act (NEPA) before final decisions are made concerning the establishment of the actual charge.

EXECUTIVE SUMMARY

This report is analytical in nature. It presents results in terms of use-based charges for interim storage and disposal or disposal only services for spent fuel from commercial nuclear reactors. A reference case and sensitivity variations involving nine additional cases are calculated on the basis of a selected reference methodology. Additional cases are given which vary the calculational methodology on the reference case. The methodologies include a levelized charge methodology in which all customers are subject to the same charge regardless of the services received.

The assumptions in this report are consistent with those announced in the October 1977 spent nuclear fuel policy. The reference case described in the report does not represent a proposed charge or even a most probable charge; it is simply a case upon which a sensitivity analysis was performed to examine the impact of changes in assumptions.

The analysis presented assumes costs based on the latest DOE program information and on preliminary facility designs. It also assumes that there would be economic and other advantages to the utilities of keeping their spent fuel at their own reactor sites rather than shipping it to interim away-from-reactor (AFR) basins. Charges are based on recovery of full costs for the services rendered and are calculated to reflect the amount due at time of transfer of the spent fuel to the DOE. The same charge applies to all transfers throughout the campaign period of 1983 through 2000. No assumption is made concerr flation except that adjustments would be made to correct foı required. Payments collected in advance of spent fuel trans be discounted at 6.5% per year to allow for interest on them at the average

interest rate for marketable treasury bills, notes and bonds. The reference case results with cost center detail are shown below in 1978 dollars.

ELEMENTS OF CHARGE - REFERENCE CASE
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	104
Transportation	0	26
Encapsulation	34	28
Geologic Repository	51	42
R&D	26	26
Government Overhead	6	6
Total	117	232
Cost in mills/kw hr	0.47	0.93

Several parameters in the reference case were varied to examine the impact on the charge. The analysis included changes in demand, facilities and services, and cost assumptions. The demand variations which increased the AFR requirements generally lowered the storage portion of the charge, since the AFR's could be used more efficiently. Slipping the planned startup date of the geologic repository increased the disposal only charge. This was due mainly to a reduction in the quantity of material handled by the Government during the campaign period, thus forcing the R&D and Government overhead costs to be borne by a smaller number of customers. If demand for Government services in the assumed campaign period were significantly less than planned, it is possible

n extended campaign period would provide a more appropriate basis for the

This would support the concept of full cost recovery over a reasonable

ıd would prevent an unduly large burden on early customers. Increases

ıssumptions predictably raised the charge. With the exception of the

greatly reduced quantity cases explained above, the sensitivity cases generally resulted in charges within 20% of the reference case.

In the methodology variations, shortening the campaign period resulted in large increases in the charges, whereas considering a one repository venture caused only slight increases in the charges. The levelized charge for all customers was $129 per kilogram of heavy metal or approximately 0.52 mills per kilowatt hour of electricity generated -- 10% higher than the disposal only charge and 44% lower than the storage and disposal charge.

As in all major projects, unforeseen technological and institutional constraints could change cost estimates for the facilities and services. DOE plans to review the charge periodically and update it when necessary. However, except for inflation, no adjustments will be made to charges once commitments have been made.

1.0 INTRODUCTION

1.1 Background

On April 7, 1977, President Carter announced that the United States would defer indefinitely all commercial reprocessing of spent nuclear fuel. Other countries were also asked to join the United States in deferring use of this technology in order to evaluate alternative fuel cycles and processes which might reduce the risk of nuclear weapons proliferation.

The reprocessing deferral resulted in the requirement for increased capacity for storage of spent nuclear fuel. On October 18, 1977, the Department of Energy (DOE) announced a new spent nuclear fuel policy, approved by the President, whereby the Government proposed, under certain conditions, to take title to and store spent nuclear fuel from private power reactors. This policy was intended to provide interim spent fuel storage pending either a final decision on reprocessing or the availability of final geologic disposal facilities, while allowing costs for management of spent fuel to be confidently considered in utility rate structures.

The National Waste Terminal Storage Program was redirected to provide a geologic disposal capability regardless of whether the material is in the form of spent fuel or solidified waste from a fuel reprocessing operation.

Upon announcement of the new policy, efforts were initiated to determine a one-time charge for storage and disposal services. As the first step in this process, DOE announced plans to publish a preliminary description of a methodology and a corresponding charge in early 1978. Accordingly, DOE awarded a contract to TRW to develop a methodology and comprehensive data

base,* and commissioned Pacific Northwest Laboratories (PNL) to examine the sensitivity of the one-time charge to variations in the financial and logistical components of the calculation.** Both contractors developed a methodology and data base for calculating the one-time charge independently and in parallel.

In January, 1978, the charge development effort was reviewed by the DOE Waste Management Task Force. It was determined at that time that the basic methodology being developed for the pricing calculation, as well as the principle of full cost recovery and other generic aspects of the approach, were acceptable. The Task Force also endorsed the desirability of subjecting the results to public review at an early date. However, based on reservations about certain specific assumptions, including design features of the repository and mechanisms for addressing waste management program uncertainties, the Task Force recommended that the first issuance not be described as the "proposed charge."

After publication of the Waste Management Task Force report***, and at the request of the President, an Interagency Review Group was formed to bring to the Waste Management Program views of a much broader spectrum of concerns. This review is scheduled for completion October 1, 1978.

In the interim, this report is intended to elicit expressions of concerns or viewpoints relevant to the establishment of the charge.

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*Reference (1)
**Reference (2)
***Reference (3)

1.2 Spent Fuel Storage Program

The Department of Energy's Spent Fuel Storage Program is responsive to the fact that electric utilities which operate or plan to operate nuclear power reactors are facing a problem with regard to the availability of adequate facilities for the storage of irradiated fuel. Many utilities are expanding their storage basin capacities through reracking for compactness. Others are transferring fuel from one basin to another within their own system. New nuclear power plants are being built with larger and more compact basins. While the increased storage basin capacities will provide relief for a number of nuclear power plants, some plants still face the prospect of inadequate basin capacity for annual fuel discharge. If this happens, the reactor must shut down.

The Spent Fuel Storage Program will enable utilities to transfer spent fuel to DOE for disposal after it has cooled for a period of time and will provide a final disposal charge. Interim away-from-reactor (AFR) storage will be provided for those utilities requiring both storage and disposal services. The charge, in those cases, will reflect storage as well as disposal costs. There is considerable DOE interest in minimizing AFR storage requirements and shipments by encouraging the use of at-reactor storage by further densification and/or expansion. It is assumed that there would be economic and other advantages to the utilities of keeping their spent fuel at their own reactor sites rather than shipping it to interim AFR storage basins. Utilities with inadequate storage capability will be able to transfer spent fuel to DOE for disposal or for storage and disposal upon payment of a one-time fee.

DOE expects to provide NRC-licensed interim storage in the form of AFR water basins prior to the availability of a terminal repository. Initial storage capability is expected to be available to receive fuel in 1983.

1.2.1 Transfer Requirements

A recent Generic Environmental Impact Statement (GEIS) on Handling and Storage of Spent Reactor Fuel* by the Nuclear Regulatory Commission contains an analysis of requirements for AFR storage of spent fuel under several conditions, some of which are applicable to the charge analysis. The case chosen for use in this analysis assumes nuclear power growth to 414 GWe in year 2000 and no transshipment of fuel among utilities. It further assumes that reactor operators rerack and otherwise expand their storage basin capacities to 2.5 times their designed capacities (usually 1.4 reactor cores), and that they reserve space for discharge of one full core at all times.

Under these assumptions, the cumulative away-from-reactor storage requirements will be 980 metric tons of spent fuel in 1983, 5,500** metric tons through 1990, and 21,300** metric tons through the year 2000. All of this fuel will have been cooled for at least five years. At the same time, the utilities themselves will be storing 12,000 metric tons in 1983, 27,400 metric tons in 1990, and 73,900 metric tons in the year 2000. This schedule is presented in Table 1 and plotted in Figure 1. The NRC study does not assume the availability of a geologic repository or consider the impact that this may have on storage requirements.

*Reference (4)
**See footnote on Table 1.

TABLE 1

CUMULATIVE SPENT FUEL TRANSFER AND STORAGE REQUIREMENTS
(Metric Tons of Heavy Metal)

	NRC GEIS*			Utility Responses			Foreign
Year	Reactor Discharges	Stored at Reactors	Transfers	Reactor Discharges	Stored at Reactors	Transfers	Transfers
1978	4,526	4,436	90	4,054	4,011	43	-
1979	5,783	5,664	119	5,448	5,302	146	-
1980	7,195	7,001	194	7,117	6,738	379	-
1981	8,856	8,454	402	9,061	8,508	553	-
1982	10,800	10,141	659	11,384	10,444	940	-
1983	12,910	11,932	978	13,962	12,250	1,712	3,000
1984	15,171	13,764	1,407	16,934	14,363	2,571	3,500
1985	17,508	15,595	1,913	20,435	16,248	4,187	4,000
1986	19,852	17,334	2,518	24,468	18,809	5,659	4,600
1987	22,103	18,930	3,173	28,692	21,200	7,492	5,300
1988	25,316	21,445	3,871	33,060	23,557	9,503	6,000
1989	28,877	24,254	4,623	37,628	26,012	11,616	6,800
1990	32,837	27,364	5,473	42,358	27,989	14,369	7,800
1991	37,194	30,726	6,468				
1992	41,937	34,458	7,479				
1993	47,149	38,559	8,590				
1994	52,811	43,022	9,789				
1995	58,900	47,791	11,109				
1996	65,427	52,891	12,536				
1997	72,365	58,258	14,107				
1998	79,672	63,851	15,821				
1999	87,303	68,878	18,425				
2000	95,221	73,894	21,327				

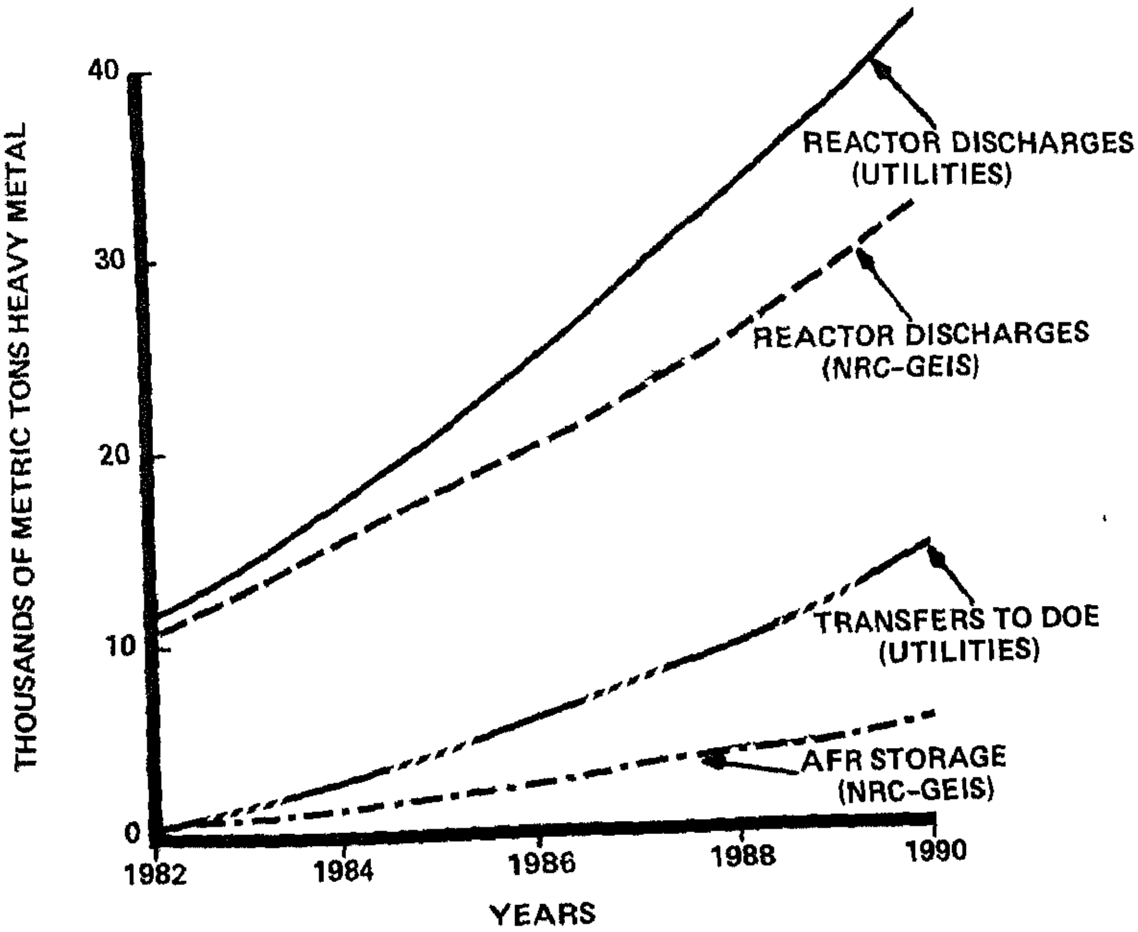
Utilities were requested to provide data through 1990 only.

*Since publication of Reference (4), the N
years 1990 through 2000 to those shown in
columns.

FIGURE 1

NEED FOR SPENT FUEL TRANSFER

UTILITY DESIRES VS. NRC GEIS REQUIREMENT



The NRC GEIS points out that through 1990, the total combined storage capacity of all reactor basins, without expansion, exceeds cumulative reactor discharges. While this space can be utilized to some extent by transshipment of fuel between reactors and between utilities, there may be limitations to doing this. From a technical standpoint, some fuel cannot be stored in basins designed for and containing fuel from other reactors without some modifications. From a practical standpoint, it is likely that utilities would be reluctant to devote their limited capacities to the storage of spent fuel from other utilities. However, transfer of fuel between reactor basins owned by the same utility is possible and is being done to temporarily delay plant shutdowns.

In December 1977, DOE sent letters of inquiry to utilities with nuclear power plants operating or under construction to determine their interest in transferring fuel to the Government through 1990 under the terms of the Spent Fuel Storage Program. The responding utilities represented approximately 98% of the reactor capacity that would be expected to have transferable fuel within that time frame. Generally, they expressed strong support for the spent fuel policy, given the indefinite deferral of reprocessing. Most indicated a desire to transfer some fuel by 1990, some wishing to begin transfer as soon as the Government would accept it. Others indicated an interest in delaying transfer until their basin capacity was fully utilized or until the fuel could be disposed of directly into a repository. On the average, the amount of fuel which utilities appear to be interested in transferring lags the reactor discharges by about seven years. The desired transfers would require the

Government to receive 1,700 metric tons in the first year (1983), growing to a cumulative total of 14,000 metric tons at the end of 1990. These quantities are shown in Table 1 and Figure 1. The desired transfers represent 43% of fuel cooled for five or more years in 1983, 60% in 1985, and 71% in 1990. The utilities would be storing 12,250 metric tons in 1983 and 28,000 metric tons in 1990.

Referring to Table 1, reactor discharges in the NRC GEIS and the Utility Responses differ because the utility data are more optimistic about the operating capacity factors of nuclear power plants and the dates at which new plants will begin commercial operation. The differences in transfers for the two studies are primarily a result of the differences in reactor discharge data. However, some utilities preferred to transfer earlier than necessary or not to expand their basins.

With regard to foreign requirements, detailed estimates are not yet available. For use in this analysis the schedule shown in Table 1 has been assumed. It is based on a relatively small percentage (10%) of the DOE forecast of discharges from foreign reactors through 1990. More recent estimates indicate that foreign demands are likely to be lower than

salt formations since there is an extensive scientific and engineering foundation for these as a result of Federally-sponsored work conducted since the late 1950's. The facility is being designed with the capability of retrievable storage for the initial operating period of five years, with subsequent operation in the disposal mode.

Although the schedule is currently under review by an Interagency Review Group, the DOE Waste Management Task Force estimated that the first geologic facility could not be operational before 1988.

2.0 SPENT FUEL STORAGE/DISPOSAL CHARGE

2.1 General Assumptions

For purposes of this analysis, several key points of the October 18, 1977, Spent Fuel Policy are considered fundamental to the development of the storage and disposal charge.

- o The charge will be a one-time charge - all liability of a utility with respect to transferred fuel will cease at the time of transfer and payment.
- o Except for emergencies, which will be considered on a case-by-case basis, the fuel shipped to the Government must be cooled a minimum of five years. Prior notification of intent to transfer is required.
- o No credit will be given for uranium or plutonium contained in the spent fuel.*
- o Transfer of fuel to the Government is voluntary.
- o Fuel transferred must be delivered to a Government-approved storage site at user expense.
- o The Government will also accept some spent fuel from foreign countries on a case-by-case basis in support of U.S. nuclear nonproliferation goals.
- o A geologic repository will be provided for initially retrievable storage

In addition, a number of generic assumptions common to the overall analysis were made. The one-time charge would be based on the recovery of the Government's costs over a reasonable time*. The charge would cover the full cost for the complete operation including interim storage, transportation from AFR to repository, encapsulaton, initial retrievable storage and terminal disposal of fuel elements. An estimate of full R&D costs would be included in the charge. Government indirect costs or overhead would also be included. The charge to be paid by utilities would be that in effect at the time of commitment and, except for inflation adjustments, would be final.

Full cost recovery has been interpreted to mean that at any point in time, the present value of revenues received during a reasonable period of time should equal the present value of costs applicable to the same period. Stated another way and in equation form,

Discounted Cost = Discounted Revenue

Since the charge per unit transfer is defined to be constant over the period,

Discounted Revenue = Charge x Discounted Spent Fuel Transfers

Therefore, the desired charge is:

$$\text{Charge} = \frac{\text{Discounted Cost}}{\text{Discounted Transfers}}$$

To calculate the charge to the user of Government services, the appropriate quantity transfers are the total fuel receiving the services within the

*The Atomic Energy Act of 1954, section 161, subsection v., concerning the establishment of prices for uranium enrichment, states that "prices for services...shall be established on a nondiscriminatory basis" and that "prices...shall be on a basis of recovery of the Government's costs over a reasonable period of time."

specified period of time, and the appropriate costs are the total costs associated with the services. Both costs and quantity transfers are discounted as described in the next paragraph and in the Appendix to this report.

There is some latitude in the application of this methodology as long as care is taken to conserve the total system balance between discounted costs and discounted revenues. Several factors must be considered and conventions established. They are given here.

a) Planning Period - The reasonable period of time over which costs and revenues are included must be selected. There are no "rules" for determining the appropriate period. In general, the period should be long enough to lessen the effects of any unusual perturbations in estimated cost or transfers, but short enough that the estimates are reliable. A campaign period of 18 years (1983 through 2000) was selected.

b) Cost Data - Projections must be made of the costs of future facilities and activities. All capital and operating costs and revenues are expressed in constant 1978 dollars. No attempt is made to account for inflation.

c) Discount Rate - The methodology requires discounting of cash flows for both costs and revenues. The discount rate should reflect the cost of capital to the operator of the services. A discount rate of 6.5% per year was used. This represents the average interest rate for marketable treasury bills, notes and bonds as of September 30, 1977, which is the

discount rate used for pricing uranium enrichment services.* Hence, any difference in the cash flows for costs and for revenues are debited or credited at the Government debt rate.

d) Discounted Costs - The "discounted costs" term of the equation must be defined. The definition used is:

Discounted Costs = Present Value of [Initial System Value + Cash Expenditures - Ending System Value]

The initial system value refers to any unrecovered costs incurred prior to the selected campaign period. The cash expenditures are those associated with managing the spent fuel received during the period, even if they are to be incurred after the end of the period. The ending system value adjusts the costs allocated to the period by taking credit for the remaining value of capital facilities at the end of the period.

e) Discounted Transfers - Projections must be made of future spent fuel transfers into the system in the form of annual material flows. The material flows are then discounted at the rate applied to costs.

Separate use-based charges which result in one charge for disposal only customers and another charge for interim storage and disposal customers were used as the basis for the reference case and the sensitivity analyses.

With use-based charges, each customer would be charged for the actual services he received. All customers would pay for disposal services but only those using the AFR would pay for that service and for the transportation from the AFR to the repository. Utility responses to DOE inquiry

*The procedure described here is the same as that used in the development of uranium enrichment prices, as are a number of other principles used in developing the spent fuel storage and/or disposal charge.

indicated that, if possible, many would prefer to delay delivery to a time when the requirements for AFR service, and hence those costs, could be avoided. This approach is consistent with the use-based charge.

Except where stated, reactors are assumed to have the characteristics shown in Table 2.

TABLE 2

REACTOR CHARACTERISTICS

- Reactor types are 1/3 BWR and 2/3 PWR.
- Reactors are assumed to have an initial test period of 2 years, to operate at a 70% capacity factor for the next 13 years, and thereafter to gradually decrease operation to a minimum of 40% capacity factor.
- Reactor parameters

	BWR	PWR
Thermal efficiency	34%	34%
Specific power, MW_{th}/MTU	24	38
Burnup, MWD_{th}/MTU	27,000	33,000
Annual discharge, MTU per 1000 MWe, (at 70% capacity factor)	28	23

2.2 Reference Case Assumptions

In addition to these general assumptions, a number of specific assumptions were required to define a reference case. Many of these specific assumptions, which have been divided into the categories of Demand, Facilities and Services, and Costs, were later varied to constitute a sensitivity analysis.

2.2.1 Demand

For the reference case, it is assumed that the transfer requirements prior to operation of the geologic repository would be those in the NRC Spent Fuel Storage GEIS for the case with no transshipment, compact

storage and full core reserve at reactor sites, as revised. No foreign fuel is included. The annual transfer schedule is shown in Table 1. This schedule assumes equilibrium reactor operation at 70% capacity factor. Once the geologic repository begins operation, it is assumed that fuel transfers to the repository would be equal to the repository's assumed acceptance rate. The material flows to the AFR and to the repository are shown in Table 3.

TABLE 3

REFERENCE CASE MATERIAL FLOWS
(Metric tons of heavy metal)

Year	Annual Transfers	Stored at AFR	Stored at Repository
1983	978	978	-
1984	429	1,407	-
1985	506	1,913	-
1986	605	2,518	-
1987	655	3,173	-
1988	698	2,071	1,800
1989	752	1,023	3,600
1990	850	73	5,400
1991	1,727	-	7,200
1992	1,800	-	9,000
1993	6,000	-	15,000
1994	6,000	-	21,000
1995	6,000	-	27,000
1996	6,000	-	33,000
1997	6,000	-	39,000
1998	6,000	-	45,000
1999	6,000	-	51,000
2000	6,000	-	57,000

2.2.2 Facilities and Services

The specific assumptions related to facilities and services that were made for the reference case were grouped into six categories or cost centers. They are:

- Away From Reactor (AFR) Storage
- Transportation
- Encapsulation Facility
- Geologic Repository
- Research and Development
- Government Overhead

The assumptions related to each cost center are described below.

2.2.2.1 Away From Reactor (AFR) Storage Facility -- The Away From Reactor Storage Facility is assumed to be a water-basin spent fuel storage facility with capacity of 5,000 metric tons (MT) of heavy metal in the form of fuel assemblies, expandable in increments of 1,000 MT to 15,000 MT with a maximum receipt rate of 2,000 MT/yr. It is assumed for economy of scale and contingency coverage that the 5,000 metric ton AFR would be the minimum facility provided by the program. The AFR would be ready to accept 5-year-old fuel 1983; the facility would be unloaded, once a geologic facility ame available, at a reasonably quick rate at the Government's venience and option. No fuel would be placed in an AFR after repository is available unless transfers from reactor basins eeded the repository receipt rate. The AFR would include a

main building, storage baskets, cooling towers, water treatment, receiving facilities for both truck and rail shipments, waste treatment, and service facilities. Standards of construction, including environmental standards, would be commensurate with commercially licensed nuclear storage facilities. The AFR is assumed to be Government financed and constructed. Operation and maintenance, surveillance, and decommissioning costs would also be included.

2.2.2.2 Transportation -- For the purpose of this analysis, the transportation of spent fuel from AFR to the repository is assumed to be accomplished entirely by dedicated trains using IF-300 casks. Freight costs were developed in accordance with the ICC Act, Part I, Section 22, which permits negotiated rates with Government agencies. The lease cost is based on a round trip of 3200 miles (estimated 1600 miles from AFR to repository) and includes five days for loading and unloading. Transportation services including casks are assumed to be provided by the private sector.

2.2.2.3 Encapsulation Facility -- The encapsulation facility is assumed to be on the site of the geologic repository and includes the buildings and equipment necessary to move LWR spent fuel from the receiving facilities of the geologic repository and place it in canisters, backfill the canisters with an intermediate heat sink, weld the canisters closed, test the canisters for leaks, and transport the canisters to temporary storage or the canistered waste

shaft of the repository. In addition, the encapsulation facility is assumed to have the capability to test and transport these canisters similar to standard canisters. Capacity is provided to process at least 6,000 MT/yr, the maximum design receiving rate of the repository. Standards of construction, including environmental standards, would be commensurate with commercially licensed nuclear facilities. The decommissioning costs for the encapsulation facility are included with the geologic repository costs.

2.2.2.4 Geologic Repository -- The geologic repository is assumed to be a 2,000-acre facility in a bedded salt formation capable of accepting spent fuel elements in 1988 at an initial design receipt rate of 1,800 metric tons of heavy metal per year with the capability of expansion to a design rate of 6,000 tons per year after five years. It would have a capacity of approximately 45,000 metric tons of heavy metal in the form of encapsulated fuel elements. Facilities are provided for mining, storing, and backfilling the salt, ventilating all shafts and tunnels, receiving spent fuel and emplacing canistered fuel in the salt with retrievability maintained for the first five years of operation. Support facilities include a diesel generator building, boiler house, and water treatment and railroad facilities.

A total of 35 million tons of salt removal, building up to a maximum removal rate of 5,600 tons per day and maintaining the maximum until completion of mine development, is assumed.

Standards of construction, including environmental standards, would be commensurate with commercial nuclear practice and mine safety requirements. Decommissioning costs and surveillance costs are also included.

2.2.2.5 Research and Development -- Government R&D funds expended in support of commercial spent fuel management are assumed to be recovered through the charge for spent fuel storage and disposal. In addition to the National Waste Terminal Storage (NWTS) program, major programs included the Lyons, Kansas Project, The Encapsulation Program, and the Spent Unreprocessed Fuel Facility Program. Costs are included for R&D related to the alternative geologic media which are being considered. Costs are also included relating to management and to the terminal storage projects at DOE's Office of Waste Isolation, Nevada Operations, and Richland Operations. No attempt has been made to estimate R&D costs beyond 1986.

2.2.2.6 Government Overhead -- Government overhead is comprised of all non-R&D expenses of the Government directly associated with the program. As a preliminary conservative estimate, the Government overhead associated with the uranium enrichment program is assumed. For the actual charge computation, overhead costs directly attributable to the Spent Fuel and Waste Management Programs will be estimated. They may be lower than the estimate used here.

2.2.3 Costs

The referenced PNL and TRW reports* served as the principal sources of cost data. These costs were based upon the latest DOE program information. Facility costs were, for the most part, based upon preliminary facility designs and include a 20 to 25% engineering contingency. For the convenience of the reader, the major cost assumptions are summarized in Table 4.

2.3 Reference Case Results

Using the given assumptions, reference charges were calculated, as previously stated, by equating the present value of total system costs to the present value of total revenues over the campaign, using a 6.5% discount rate. The resulting charges reflect in 1978 dollars the amount due per kilogram of spent fuel transferred to the DOE. The charges quoted are those due at the time of transfer. The same charge applies to all transfers throughout the campaign period of 1983 through 2000. The charges are:

for disposal only	$117/kg heavy metal;
for storage and disposal	$232/kg heavy metal.

Table 5 shows how these values would change as a function of time, if payments were made in advance of transfer assuming a 6.5% discount rate. For example, if in 1978 a utility were to make a commitment to transfer in 1988 one annual discharge of spent fuel for disposal only, the charge would be $62 per kilogram ($117/kg discounted for 10 years). If the discharge were 25 metric tons, the total payment in 1978 would be $1.55 million. That payment would earn interest at the rate of 6.5% per year and would amount to $2.9 million at time of transfer in 1988. Adjustments for inflation would be made at that time and any

*References (1) and (2).

TABLE 4

SUMMARY OF COST ASSUMPTIONS
(Millions of 1978 Dollars)

	Facility	Annual Operating Cost	Capital Cost	Other Cost
AFR	5,000 MTU* (2000 MTU/yr receipt rate)	6	200	20 (decommissioning)
	1,000 MTU expansion	-	20	-
Transportation	AFR to repository site	-	-	0.0315/MTU
Encapsulation Facility	6,000 MTU/yr receipt rate	21	350	0.004/canister
Geologic Repository	45,000 MTU (6000 MTU/yr receipt rate)	50	500	0.005/canister 200 (decommissioning)
Research and Development	Total through 1986	-	-	560
Government Overhead	Annual	13	-	-

*MTU represents the quantity of uranium in metric tons contained in the fresh fuel elements prior to loading into a reactor. This is essentially the same as the quantity of heavy metal (uranium plus plutonium) contained in the same fuel elements after discharge from the reactor.

TABLE 5

Payment for Spent Fuel Storage and/or Disposal Charge if Payments are Made in Advance of Transfer

(6.5 percent per year discount rate)

Number of Years in Advance That Payment is Made	Fraction	Reference Case: Disposal Only	Reference Case: Storage and Disposal
0	1.00	117	232
1	.94	110	218
2	.88	103	205
3	.83	97	192
4	.78	91	180
5	.73	85	169
6	.69	80	159
7	.64	75	149
8	.60	71	140
9	.57	66	132
10	.53	62	124

additional payments would be due then. Similarly, payment in 1978 for storage and disposal with transfer in 1983 would be \$169/kg (\$232/kg discounted for 5 years). For a 25 metric ton discharge, the total payment in 1978 would be \$4.22 million which would amount to \$5.8 million in 1983 at time of transfer. Here again, adjustments for inflation would be due at time of transfer.

The elements of the reference case charge calculations are shown below. The actual costs for disposal are the same for all fuel. However, the encapsulation and repository costs are discounted for a greater number of years in the storage-and-disposal case than in the disposal only case. This accounts for the difference between \$34 and \$28 per kg for encapsulation and \$51 and \$42 per kg for the repository as explained in the Appendix. R&D costs and Government overhead costs are allocated equally to all customers. By definition of use-based charges, the AFR and transportation from AFR to repository are elements of the storage and disposal charge but not of the disposal only charge.

ELEMENTS OF CHARGE - REFERENCE CASE
(\$/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	104
Transportation	0	26
Encapsulation	34	28
Geologic Repository	51	42
R&D	26	26
Government Overhead	6	6
Total	117	232
Cost in mills/kw hr*	0.47	0.93

*The conversion of the charge into mills/kw hr is dependent on the thermal efficiency of the nuclear power plant and the burnup of the fuel. The conversion factor used here (\$250/kg = 1 mill/kw hr) is based on an average thermal efficiency of 34% and an average burnup level of 31,000 MWD_{th}/MTU. These represent average design levels for reactors currently being built. This would be added to the nuclear power electricity costs which are now about 40 mills per kilowatt hour to the consumer.

The reference case required 3,200 metric tons of AFR storage, filled the first geologic repository in the late 1990's, and introduced 12,000 metric tons of spent fuel into a second geologic repository. The AFR was unloaded in the early 1990's and reactor basin fuel inventories were gradually reduced so that by 2000 they retained five to six annual discharges. A total of 57,000 metric tons of spent fuel was loaded into the geologic repositories.

The method of charging employed here recovers full costs to the Government for the services provided. It is not a method of "indifference pricing" to the utilities. Each utility has its own unique spent fuel storage needs, capabilities and financial circumstances. The cost for providing interim storage for spent fuel elements at a particular reactor may be quite different from that element in the storage and disposal charge applicable to interim AFR storage. Even in cases where there is no difference, the transportation from AFR to repository in the storage and disposal charge has no counter-part for disposal only customers. Furthermore, the transfer of fuel directly to the repository rather than first to the AFR has the effect of delaying the cost of transportation from the reactor basin to the Government site, which could be a significant factor for some utilities. All of these factors would be important to utilities considering additional storage space. If, as a result of the lower charge, the request for disposal-only transfers, were to exceed the repository receipt rate, customers would have to be accepted on some priority basis.

3.0 SENSITIVITY ANALYSIS

In order to examine the sensitivity of the one-time charge to variations in the assumptions, parameters in the reference case were selectively varied and the magnitude of the impact on the results were noted. Demand, facilities and services, and cost assumptions were systematically examined.

3.1 Case Descriptions

A brief description of each change to the reference case is given in Table 6. Details are given with the results.

3.2 Results

The results of the individual sensitivity analyses are presented in detail in this section. They can be compared by referring to Table 7 and Figures 2 and 3. Figure 2 presents the use-based charge results for disposal only, Figure 3 for storage and disposal.

TABLE 6

DESCRIPTION OF SENSITIVITY ANALYSIS CASES

SENSITIVITY CASE NO.	DESCRIPTION
	DEMAND VARIATIONS
(1)	Lower demand - use of the NRC GEIS demand for transfers throughout the period 1983-2000 (Table 1).
(2)	Earlier demand - use of the NRC GEIS reactor discharge schedule (Table 1) cooled exactly five years throughout the period 1983-2000.
(3)	Fuel transferred to Government as indicated by utility responses (Table 1) in place of the reference case demand prior to 1988.
(4)	Foreign participation in program - 10% of foreign spent fuel cooled 5 years (Table 1) in addition to the reference case demand prior to 1988.
	FACILITIES AND SERVICES VARIATIONS
(5)	Geologic repository planned for 1993 startup
(6)	Geologic repository capacity - 100,000 MTU
	COST VARIATIONS
(7)	Privately financed AFR
(8)	Capital costs increased by 25%
(9)	R&D costs increased by 25%

TABLE 7

SUMMARY OF CASE RESULTS

	Services: Disposal (MTU)	Services: AFR Storage (MTU)	Use-based Charge: Disposal Only ($/kg)	Use-based Charge: Storage and Disposal ($/kg)
Reference Case	57,000	3,173	117	232
Demand Variations				
1. Lower demand	21,327	3,173	214	319
2. Earlier demand	58,900	13,103	117	144
3. Utility responses	57,000	10,690	115	165
4. Foreign participation	57,000	5,073	117	187
Facilities and Services Variations				
5. Repository planned for 1993 startup	27,000	7,479	160	202
6. Repository capacity 100,000 MTU	57,000	3,173	112	227
Cost Variations				
7. Privately financed AFR	57,000	3,173	117	276
8. Capital costs increased by 25%	57,000	3,173	128	262
9. R&D costs increased by 25%	57,000	3,173	123	238

FIGURE 2

USE-BASED CHARGE — DISPOSAL ONLY

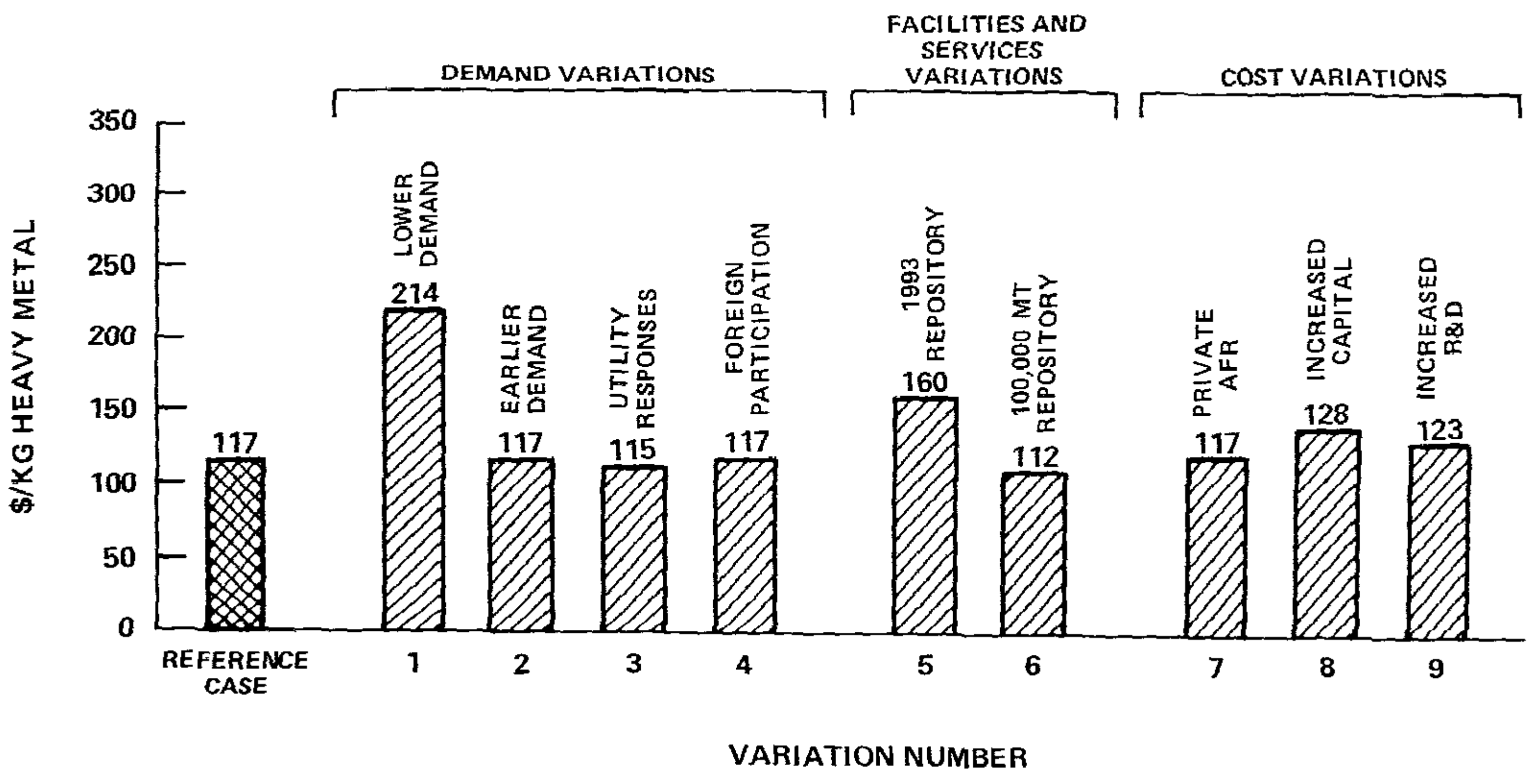
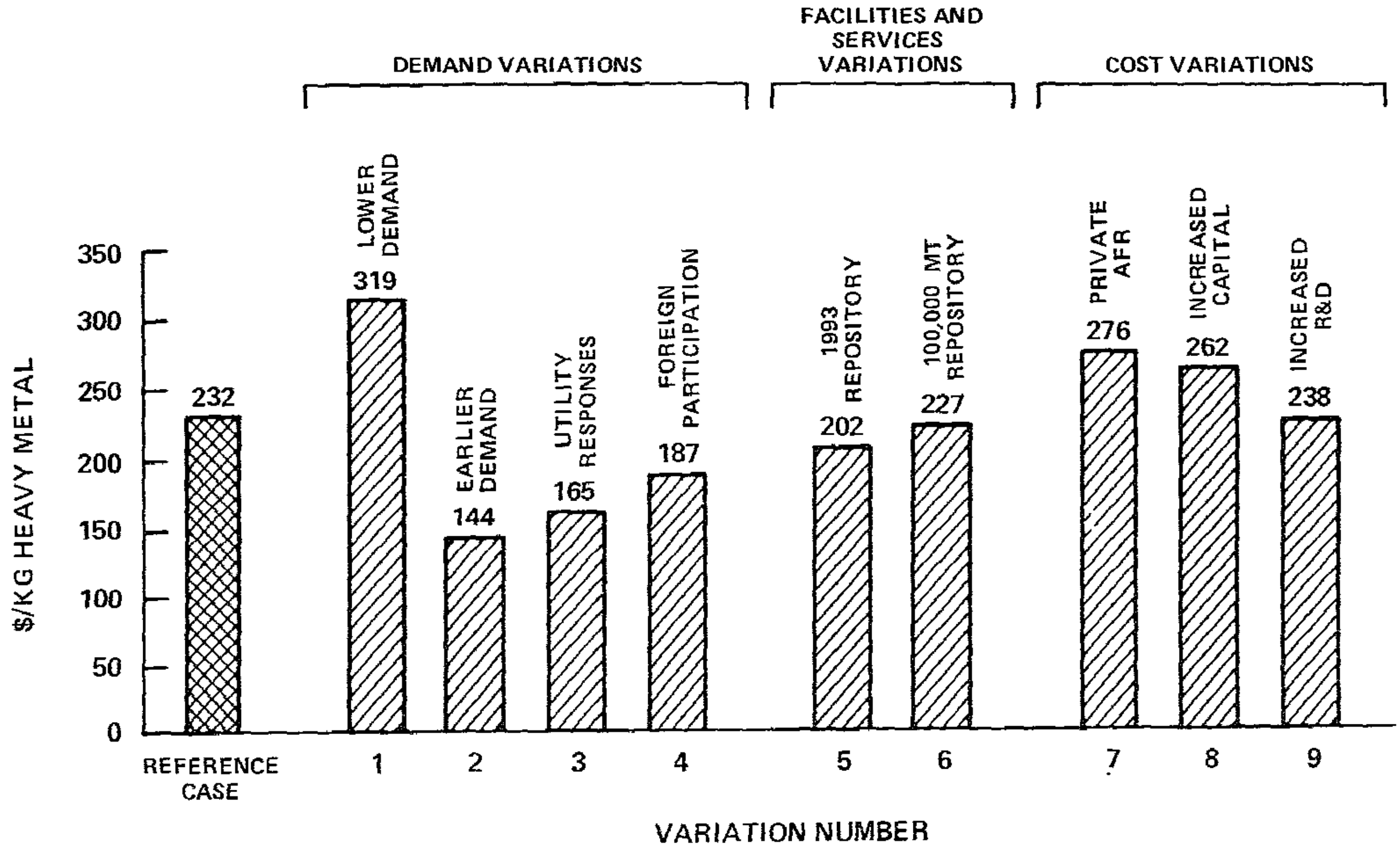


FIGURE 3
USE-BASED CHARGE — STORAGE AND DISPOSAL



3.2.1 Demand Variations

Lower Demand. Lowering the demand has the expected effect of dramatically increasing the charge both to disposal only customers and to storage and disposal customers. The AFR requirement remains 3,200 metric tons as expected, but the geologic repository receipt rate is considerably lowered to a total of 21,300 metric tons and reactor basins remain full except for the space reserved for the full cores. In cases such as this in which the total demand is significantly changed, an adjustment to the campaign period would be appropriate for "recovering Government costs for these services over a reasonable period of time." However, no such extension of the campaign period was assumed in the results provided here.

ELEMENTS OF CHARGE - LOWER DEMAND
(\$/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	104
Transportation	0	26
Encapsulation	49	40
Geologic Repository	87	71
R&D	64	64
Government Overhead	14	14
Total	214	319
Cost in mills/kw hr	0.86	1.28

Earlier Demand. Increasing the demand has the expected effect of lowering the charge. This case provides earlier transfer of fuel than the reference case, and therefore requires 13,100 metric tons of AFR storage. However, the quantity of spent fuel ultimately disposed of in the geologic facilities (58,900 metric tons) is only slightly greater than in the reference case; hence, the effect on the disposal only charge is not noticeable. The AFR portion of the charge is significantly lower since that cost, though greater than in the reference case, is borne by a greater number of customers.

ELEMENTS OF CHARGE - EARLIER DEMAND
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	48
Transportation	0	18
Encapsulation	36	20
Geologic Repository	54	31
R&D	22	22
Government Overhead	5	5
Total	117	144
Cost in mills/kw hr	0.47	0.58

Utility Responses. The use of the fuel transfers identified by utilities in response to DOE's December, 1977 letter results in increased transfers through 1987, thus requiring 10,700 metric tons of AFR storage. The total demand for geologic disposal remains the same as in the reference case. The charge for storage and disposal is reduced considerably, compared to the reference case. The disposal only charge is reduced somewhat by slightly earlier revenue receipts, as evidenced by the greater AFR requirement.

ELEMENTS OF CHARGE - UTILITY RESPONSES
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	60
Transportation	0	20
Encapsulation	34	22
Geologic Repository	52	34
R&D	24	24
Government Overhead	5	5
Total	115	165
Cost in mills/kw hr	0.46	0.66

Foreign Participation. To examine the effect of foreign participation, the assumption was made that 10% of the foreign reactor discharges, if cooled 5 years or more, would be shipped to the U.S. through 1990. No assumption was made for handling foreign fuel differently from domestic fuel. The results show that the degree of foreign interest affects AFR requirements proportionally, and the inverse effect of demand for AFR facilities on the use-based storage and disposal charge is again observed. No effect is seen on the disposal only charge because of the assumption to have the repository receive spent fuel at its assumed acceptance rate.

ELEMENTS OF CHARGE - FOREIGN PARTICIPATION
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	70
Transportation	0	23
Encapsulation	34	24
Geologic Repository	51	38
R&D	26	26
Government Overhead	6	6
Total	117	187
Cost in mills/kw hr	0.47	0.75

3.2.2 Facilities and Services Variations

Repository Planned for 1993 Startup. A "planned delay" in the geologic repository startup date has the effect of increasing the AFR requirement to 7,500 metric tons and lowering the total quantity transferred during the campaign period to only 27,000 metric tons. The disposal-only

charge is increased as in the previous lower demand case. However, contrary to that case, the use-based storage and disposal charge is decreased. This is a result of the more efficient use of AFR facilities brought about by the increased demand for them. Here again, perhaps a longer campaign period would be more appropriate.

ELEMENTS OF CHARGE - 1993 REPOSITORY
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	63
Transportation	0	18
Encapsulation	34	20
Geologic Repository	60	35
R&D	54	54
Government Overhead	12	12
Total	160	202
Cost in mills/kw hr	0.64	0.81

100,000 Metric Ton Repository Capacity. The effect of the assumption that the geologic repository is conservatively loaded to a capacity of 45,000 MTU in the reference case is demonstrated by comparison with the analysis of a repository less conservatively loaded with an ultimate capacity of 100,000 MTU. Increasing the capacity essentially eliminates the need for a second repository during the campaign period and lowers the charge slightly.

ELEMENTS OF CHARGE - 100,000 MT REPOSITORY
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	104
Transportation	0	26
Encapsulation	31	26
Geologic Repository	49	39
R&D	26	26
Government Overhead	6	6
Total	112	227
Cost in mills/kw hr	0.45	0.91

3.2.3 Cost Variations

Private AFR. The effect of private instead of Government financing of the AFR is an increase in the use-based charge for storage and disposal but not in the disposal only charge. This is due to the difference in cost of capital assumed for the two sectors, i.e., 6.5% for Government financing and 12% for private.

ELEMENTS OF CHARGE - PRIVATE AFR
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	
Transportation	0	
Encapsulation	34	
Geologic Repository	51	42
R&D	26	26
Government Overhead	6	6
Total	117	276
Cost in mills/kw hr	0.47	1.10

Increased Capital and R&D Costs. The sensitivity of the reference charge to increases in capital and R&D costs had the predictable effect of increasing the charge.

ELEMENTS OF CHARGE - CAPITAL COSTS INCREASED 25%
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	126
Transportation	0	26
Encapsulation	38	31
Geologic Repository	58	47
R&D	26	26
Government Overhead	6	6
Total	128	262
Cost in mills/kw hr	0.51	1.05

ELEMENTS OF CHARGE - R&D COSTS INCREASED 25%
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	104
Transportation	0	26
Encapsulation	34	28
Geologic Repository	51	42
R&D	32	32
Government Overhead	6	6
Total	123	238
Cost in mills/kw hr	0.49	0.95

3.2.4 AFR Requirements and Total Demand

e 4 and Table 7 show the relative impacts of the various sensitivity on the requirements for interim spent fuel storage capacity,

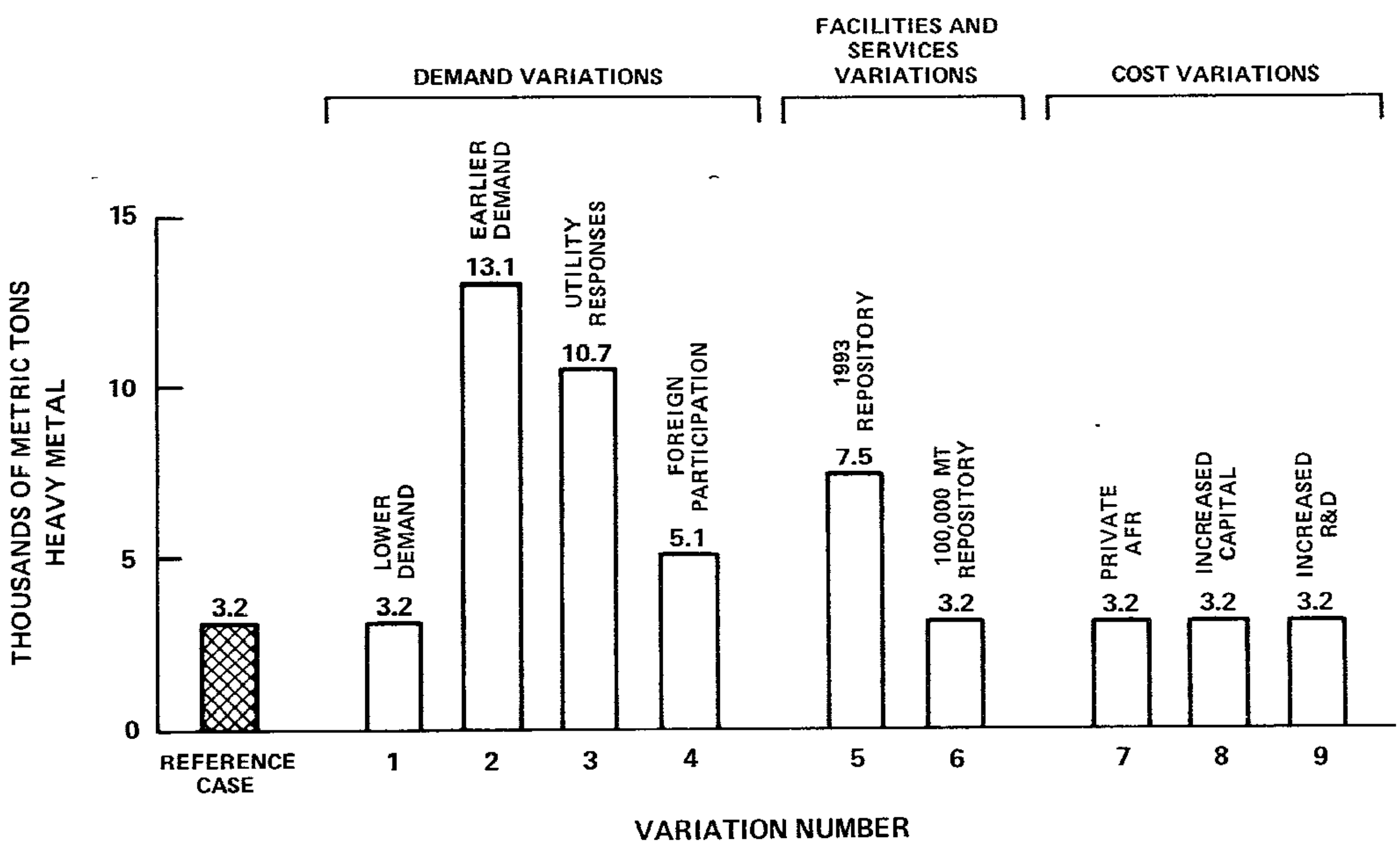
where as much as 13,100 metric tons or as little as 3,200 metric tons may be required. Table 7 also shows the total demand for the geologic facility in each of these cases.

3.3 Summary of Sensitivity Analyses

Some general observations related to the results of these sensitivity analyses can be made. The most significant impact occurs as a result of large changes in the total transfer of spent fuel during the campaign period. The calculated storage-and-disposal charge is more sensitive to variations which affect near-term receipts than is the disposal only charge. The charges are relatively insensitive to the capacity of the first repository. The effect of delaying the first repository to 1993 is significant primarily because of the lowered demand.

One final observation with respect to the sensitivity analyses involves the question of contingency. It is likely that, for the actual published charge, a contingency will be added. The use of such a factor is intended to cover normal and usual events and is not intended as protection against major unforeseen events. The sensitivity analyses examined the impact of a representative sample of conceivable events. It is noteworthy that in all cases except those in which the total demand was significantly lowered, a contingency of 20 percent would be adequate to cover the resulting change in charge. For the cases with lower demand, a much greater contingency (up to 85%) would be required and a change in the campaign period over which costs would be recovered would seem to be more appropriate.

FIGURE 4
AFR REQUIREMENTS



4.0 ALTERNATIVE METHODOLOGIES

The reference case and the sensitivity analyses used the same basic methodologies. They assumed that the cost of all system elements required to manage spent fuel received through an arbitrarily chosen horizon year (the year 2000) would be recovered nondiscriminantly from all customers of record during that period.

The impact of varying the campaign length was also examined. A shorter time period (through 1992 instead of 2000) resulted in a much higher charge. Since this assumption does not impact AFR requirements and costs, but does reduce the total demand to only 9,000 metric tons during the campaign, the increased charges result from averaging costs over a smaller base.

ELEMENTS OF CHARGE - CAMPAIGN THROUGH 1992
($/kg Heavy Metal)

	Use-based Charge	
	Disposal Only	Storage and Disposal
AFR	0	104
Transportation	0	26
Encapsulation	50	40
Geologic Repository	88	73
R&D	58	58
Government Overhead	17	17
Total	213	318

AFR requirements: 3,200 metric tons heavy metal

Total transfers: 9,000 metric tons heavy metal

4.1 Venture Methodology

This alternative approach was called the venture methodology because it approximates the treatment of a single project, the first repository with 45,000 MT capacity, as a single entity. This eliminates the need for assumptions about the second repository and at the same time preserves the concept of conservatively loading the first repository. It should be noted that additional repositories will be needed eventually, and an orderly transition from the initial venture to subsequent repositories would be required.

This case resulted in a slight increase in the charges since costs were borne by a somewhat smaller quantity of spent fuel. A comparison of these charges with those of the reference case and the shortened campaign period can be seen in Figure 5.

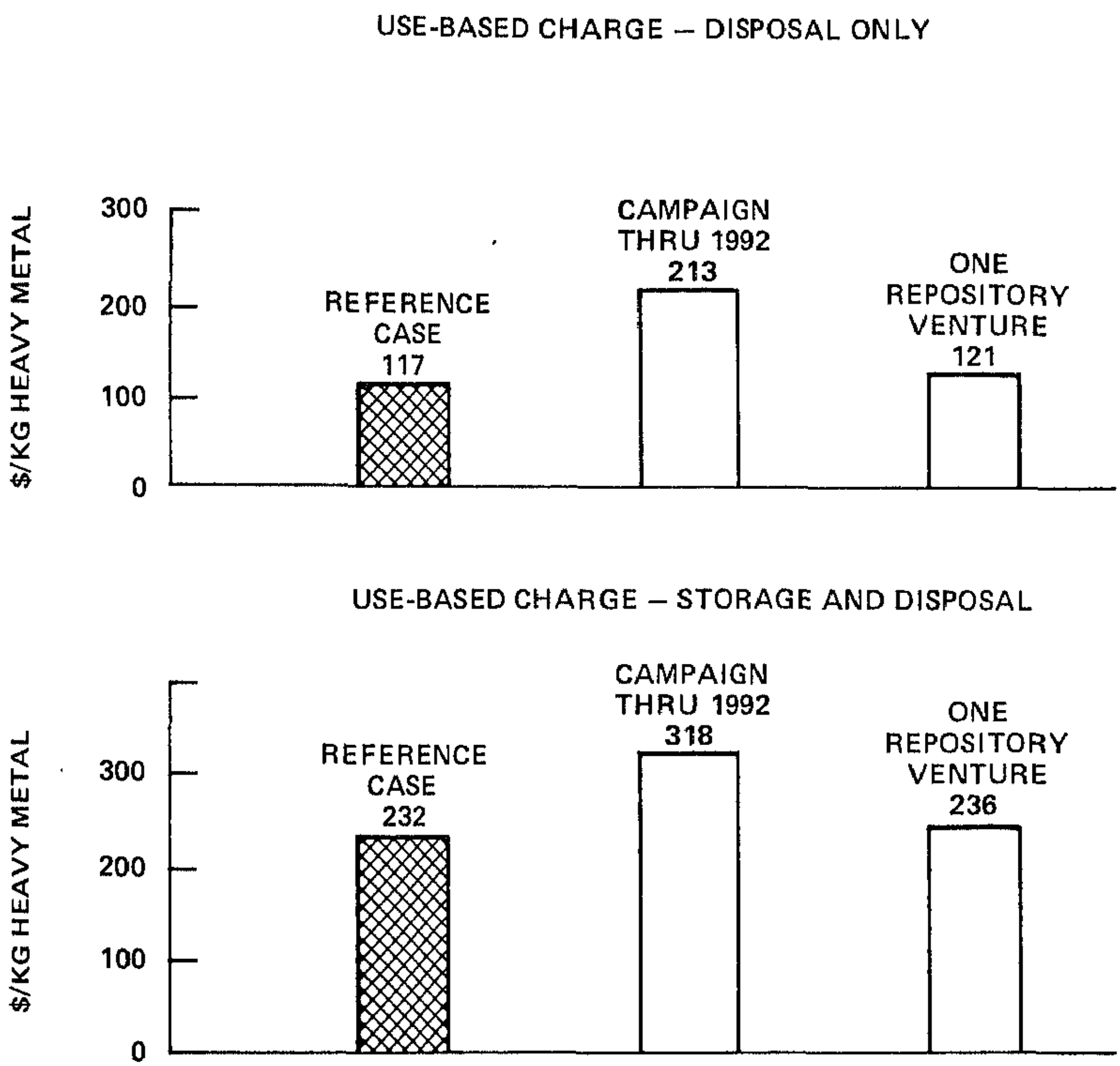
ELEMENTS OF CHARGE - ONE REPOSITORY VENTURE
($/kg Heavy Metal)

	Disposal Only	Storage and Disposal
AFR	0	104
Transportation	0	26
Encapsulation	32	26
Geologic Repository	50	41
R&D	32	32
Government Overhead	7	7
Total	121	236

requirement: 3,200 metric tons heavy metal

.al transfers: 45,000 metric tons heavy metal

FIGURE 5
ALTERNATIVE METHODOLOGIES CHARGES



4.2 Levelized Charge Methodology

With the levelized charge, all customers would be charged at the same rate regardless of the disposition of their particular fuel. As a result, under the levelized charge, customers who deliver fuel in the later period when fuel is being deposited in the repository without prior AFR storage, also would pay a charge which included a component for AFR storage and transportation from the AFR to the repository. At the same time, earlier customers whose fuel must be stored in the AFR prior to repository availability would be charged a correspondingly lower charge for AFR storage and transportation from AFR to repository.

ELEMENTS OF CHARGE - LEVELIZED CHARGE
($/kg Heavy Metal)

	Reference Case		
	Levelized Charge	Use-based Charge	
		Disposal Only	Storage and Disposal
AFR	11	0	104
Transportation	3	0	26
Encapsulation	33	34	28
Geologic Repository	50	51	42
R&D	26	26	26
Government Overhead	6	6	6
Total	129	117	232
Cost in mills/kw hr	0.52	0.47	0.93

AFR requirement: 3,200 metric tons heavy metal

Total transfers: 45,000 metric tons heavy metal

5.0 UNFORESEEN EVENTS AFFECTING CHARGE

The charges estimated in this document have been calculated under the assumption that the technologies involved will be found institutionally and environmentally acceptable. Furthermore, it was assumed that construction of the required facilities would proceed according to whatever schedule is adopted. As in all major projects, the cost estimates could change as a result of slippages in construction schedules or changes in specifications.

Small variations in costs and schedules beyond that already provided for in the cost estimates can probably be absorbed through the use of a contingency factor attached to the one-time charge for all customers. The sensitivity analysis in Section 3 would indicate that a 20% contingency factor could be used.

Even so, periodic review of the costs and anticipated demand can be expected and adjustments to the charge will be made when required. It is possible that two or more variations in costs and schedules would offset each other. For example, increases in facility costs could be offset by increased demand. In that case no charge adjustment would be necessary.

Greater variations such as might be caused by an unplanned delay in the availability of the first geologic repository or a failure in its operation may not be covered by a contingency factor. Schedule overruns would involve additional costs. Increased AFR storage requirements could involve construction of additional AFR facilities or expansions of existing ones. Temporary dry above-ground storage which could be provided instead of additional AFR

space and which would be necessary for storage of fuel retrieved from the repository would involve substantial capital outlays. It is possible that such additional costs would be borne equally by future customers. In any case, the occurrence of any such major event would mandate a revision of the charge.

Although no adjustments would be made to the charges in commitments already made, all future commitments would reflect the revised charges.

APPENDIX - METHODOLOGY FOR CALCULATING CHARGE

Basic to the charge calculation methodology is the principle that the Government should be reimbursed over a reasonable period of time for all costs relevant to the services provided. This has been interpreted to mean that the present value of all applicable revenues must equal the present value of all relevant costs. Stated another way,

Discounted Costs = Discounted Revenues

All costs and revenues are expressed in constant dollars. Costs are recognized at the beginning of the year incurred. Revenues are recognized at the end of the year that spent fuel is received at a site designated by the Government. For the reference case in this analysis a campaign through year 2000 is taken as a reasonable period of time. The discount rate is constant throughout the period.

Since revenue is defined as charge multiplied by quantity and since the charge is defined to be a constant over the campaign period, discounted revenue can be expressed as,

Discounted Revenue = Charge x Discounted Quantity

As a result, the desired charge in terms of doll

be calculated by the formula

$$\text{Charge} = \frac{\text{Discounted Cost}}{\text{Discounted Quantity}}$$

Discounted Quantity is determined by first projecting annual transfers of spent fuel to the designated site, then discounting them to the present year at the accepted Government discount rate, and finally summing the discounted quantities. This is expressed by the formula,

$$Q = \sum_{t=1}^{t=n} \frac{Q_t}{(1+r)^t},$$

where Q = sum of discounted quantity transfers

Q_t = transfers for year t

r = discount rate

t = year (t=1 represents present year)

n = last year of campaign

Discounted costs are determined by first projecting annual cash expenditures for capital and operating costs for each cost center including those dependent on material flows, then discounting them to the present year at the accepted rate, and finally summing the discounted annual costs by cost centers. This is expressed by the formula,

$$C_i = \sum_{t=1}^{t=n} \frac{C_{it}}{(1+r)^{t-1}},$$

where C_i = sum of discounted costs for cost center i,*

C_{it} = cash expenditure in year t for cost center i.

*Cost centers are: 1. AFR; 2. transportation from AFR to repository; 3. encapsulation; 4. geologic repository; 5. R&D; 6. Government overhead.

Any unrecovered costs incurred prior to the campaign period (referred to elsewhere in the report as initial system value) are included as costs in the first year. The cash expenditures are those for managing the program during the period and include costs associated with managing all the spent fuel received during the period even those relevant costs incurred after the end of the period. Decontamination and decommissioning costs are included in the years following the last year of operation of the facility. If the facility is held open beyond the end of the campaign period, these costs are recognized in the last year of the campaign period, except that no such costs are recognized during the campaign period for the second repository. Any costs incurred during the period which are associated with the remaining value of capital facilities at the end of the period are accumulated as an ending system value and credited against the costs in the last year of the campaign.

Direct application of the methodology described constitutes a levelized charge, by which all customers are charged the same fee regardless of service rendered. The component of the charge associated with each cost center is calculated in terms of $ per kilogram by the formula,

$$P_i = C_i \;/\; Q,$$

where P_i is the charge component for cost center i.

The total charge in terms of $ per kilogram is the sum of the six cost center components.

$$P = \sum_{i=1}^{i=6} P_i,$$

where P = total charge

P_1 = AFR component of charge

P_2 = transportation component

P_3 = encapsulation component

P_4 = geologic repository component

P_5 = R&D component

P_6 = Government overhead component

For use-based charges, the costs associated with each cost center are allocated to the appropriate customers in proportion to their use. All costs for the AFR and the transportation from the AFR to the repository are charged to the users of those services. The encapsulation and repository costs are allocated according to use and time of payment. R&D costs and Government overhead are shared equally by all customers.

The discounted quantities transferred to the AFR for storage and disposal and directly to the repository for disposal only are calculated according to the formulas,

$$Q_A = \sum_{t=1}^{t=n} \frac{Q_{At}}{(1+r)^t} ,$$

$$Q_D = \sum_{t=1}^{t=n} \frac{Q_{Dt}}{(1+r)^t} ,$$

where Q_A = sum of discounted transfers to the AFR

Q_D = sum of discounted transfers for disposal only

Q_{At} = receipts at AFR during year t

Q_{Dt} = disposal only receipts at repository during year t

Note that $Q_A + Q_D = Q$.

The components of the charge for the AFR (P_1) and for transportation (P_2) chargeable to the users of those services under the use-based philosophy are, therefore,

$$P_1 = C_1 / Q_A \quad ,$$
$$P_2 = C_2 / Q_A \quad .$$

The components of the charge for those services to the disposal only customers are zero.

In order to apportion the costs of encapsulation and the repository facility to the two types of customers and to account for earlier payments made by storage and disposal customers, the quantities transferred from the AFR to the repository were determined and discounted to the present year. Transfer from AFR to repository was assumed to take place at the beginning of each year, which is consistent with the assumption that cc the beginning of each year. The formula expressing 1

$$Q_T = \sum_{t=1}^{t=n} \frac{Q_{Tt}}{(1+r)^{t-1}},$$

where Q_T = sum of discounted transfers fror

Q_{Tt} = transfers from AFR to reposito

The ratio Q_T/Q_A represents the discounting factor for the payment of encapsulation and repository charges in advance of receipt of those services. It is expressed by the formula,

$$\frac{Q_T}{Q_A} = \frac{1}{(1+r)^s}$$

where s = on the average, the number of years that transfers for storage and disposal remain in the AFR.

The components of the charge for those services (P_3, P_4) to each type of customer are calculated according to the formulas given below.

For disposal only,

$$P_{3(D)} = C_3 \times \left(\frac{Q_D}{Q_T + Q_D}\right) \Big/ Q_D = C_3 \;/\; (Q_T + Q_D)$$

$$P_{4(D)} = C_4 \times \left(\frac{Q_D}{Q_T + Q_D}\right) \Big/ Q_D = C_4 \;/\; (Q_T + Q_D)$$

For storage and disposal,

$$P_{3(A)} = C_3 \times \left(\frac{Q_T}{Q_T + Q_D}\right) \Big/ Q_A = \left[C_3 \;/\; (Q_T + Q_D)\right] \times \frac{Q_T}{Q_A}$$

$$P_{4(A)} = C_4 \times \left(\frac{Q_T}{Q_T + Q_D}\right) \Big/ Q_A = \left[C_4 \;/\; (Q_T + Q_D)\right] \times \frac{Q_T}{Q_A}$$

Note that algebraic manipulation of these formulas reveals the fact that the disposal only charge components for these services can be calculated by dividing the total cost for each cost center by the sum of the discounted transfers to disposal only and from AFR to repository. Similarly, the storage and disposal charge components for these services can be calculated by multiplying each disposal only charge component by the discounting factor ratio Q_T/Q_A.

The charge components for R&D and for Government overhead are the same to all customers and are calculated as for the levelized charge,

$$P_5 = C_5 / Q$$
$$P_6 = C_6 / Q$$

The total charge to disposal only customers is the sum of the charge components applicable to them,

$$P_D = P_{3(D)} + P_{4(D)} + P_5 + P_6$$

The total charge to the storage and disposal customers is the sum of the components applicable to them,

$$P_A = P_1 + P_2 + P_{3(A)} + P_{4(A)} + P_5 + P_6$$

An example of this methodology is shown for the reference case. Annual cash expenditures are shown by components in Table A-1. Their present values in 1978 are shown in the bottom line. The revenues anticipated for this case are also shown in Table 1 and their present values also appear in the bottom line. Notice that the present values of costs and revenues are indeed equal.

The formulas previously given applied to the transfers shown in Table 3 of this report produce the following discounted quantities.

$$Q_A = 1{,}944 \text{ metric tons}$$

$$Q_D = 16{,}697 \text{ metric tons}$$

$$Q = Q_A + Q_D = 18{,}641 \text{ metric tons}$$

$$Q_T = 1{,}590 \text{ metric tons}$$

The formulas for allocating the costs to the two types of customers and calculating the charge components applied to the costs in Table A-1 using the discounted quantities shown above produce the results shown in Table A-2. For example:

To arrive at the charge component for AFR services,

$$P_1 = C_1/Q_A = (\$202 \times 10^6) \Big/ (1.944 \times 10^6\text{kg}) = \$104/\text{kg}.$$

To apportion the encapsulation costs to the two types of customers and arrive at those charge components,

$$P_{3(D)} = C_3 \times \left(\frac{Q_D}{Q_T + Q_D}\right) \Big/ Q_D = (\$613 \times 10^6) \times \left(\frac{16.697}{1.590 + 16.697}\right) \Big/ (16.697 \times 10^6\text{kg})$$

$$= 559/16.697 = \$34/\text{kg},$$

$$P_{3(A)} = C_3 \times \left(\frac{Q_T}{Q_T + Q_D}\right) \Big/ Q_A = (\$613 \times 10^6) \times \left(\frac{1.590}{1.590 + 16.697}\right) \Big/ (1.944 \times 10^6\text{kg})$$

$$= 54/1.944 = \$28/\text{kg}.$$

Table A-1

REFERENCE CASE CASH FLOWS FOR COSTS AND REVENUES
($ millions)

	Costs							Revenues		
	AFR	Transportation	Encapsulation	Repository	R&D	Overhead	Total	Storage & Disposal	Disposal Only	Total
1977					40		40			
1978					86		86			
1979	10				120		130			
1980	15				98		113			
1981	71			5	93		169			
1982	105			20	76		201			
1983	6			80	28	13	127	227		227
1984	6		139	125	9	13	292	100		100
1985	6		121	110	6	13	256	117		117
1986	6		51	85	4	13	159	140		140
1987	6		35	75		13	129	152		152
1988	6	35	37	87		13	178		82	82
1989	6	33	37	92		13	181		88	88
1990	6	30	37	90		13	176		99	99
1991	6	2	37	93		13	151		202	202
1992	20		37	154		13	224		211	211
1993			284	214		13	511		702	702
1994			256	192		13	461		702	702
1995			152	167		13	332		702	702
1996			127	156		13	296		702	702
1997			107	156		13	276		702	702
1998			107	171		13	291		702	702
1999			107	161		13	281		702	702
2000			-346	-92		13	-425		702	702
Total	275	100	1325	2141	560	234	4635	736	6298	7034
Discounted to the beginning of 1978	202	50	613	934	497	106	2402	450	1952	2402
	C_1	C_2	C_3	C_4	C_5	C_6		$Q_A x P_A$	$Q_D x P_D$	

Table A-2

CALCULATION OF CHARGE ELEMENTS FOR REFERENCE CASE

	For Disposal Only			For Storage and Disposal	
Cost Center	Total Costs Discounted to 1978	Discounted Costs ($ millions)	Charge ($/kg)	Discounted Costs ($ millions)	Charge ($/kg)
AFR	202	0	0	202	104
Transportation	50	0	0	50	26
Encapsulation	613	559	34	54	28
Repository	934	852	51	82	42
R&D	497	446	26	51	26
Government overhead	106	95	6	11	6
Total	2,402	1,952	117	450	232
Transfers Discounted to 1978 (metric tons)	18,641	16,697		1,944	

REFERENCES

(1) "Economics of National Waste Terminal Storage, Spent Fuel Pricing Study," Y/OWI/SUB-78/42512/2, TRW Energy Systems Planning Division, May 1978.

(2) "Sensitivity of the Federal Fee for Managing Spent Fuel to Financial and Logistical Variations," PNL-2637, June 1978.

(3) "Report of Task Force for Review of Nuclear Waste Management" (Draft), U.S. DOE, DOE/ER-0004/D, February 1978.

(4) "Draft Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Reactor Fuel," U.S. Nuclear Regulatory Commission, NUREG-0404, March 1978.